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WITNESS my hand this  
Eleventh day of January 2005

A handwritten signature in dark ink, appearing to be 'LA'.

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MANAGER EXAMINATION SUPPORT  
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## PROVISIONAL SPECIFICATION

Invention Title:      **Simplified Systolic and Pulse Pressure Method**

The invention is described in the following statement:

## **METHOD AND APPARATUS FOR DETERMINATION OF CENTRAL AORTIC PRESSURE**

### **FIELD OF THE INVENTION**

- 5       The present invention relates to the determination of central aortic systolic and pulse pressure from a peripheral waveform.

### **BACKGROUND OF THE INVENTION**

- 10       The relationship between systolic blood pressure in the arm and cardiovascular events is well established, and is the basis for modern therapy for hypertension. Such therapy, aimed at reducing brachial systolic pressure, has been very successful in reducing death and disability from cardiovascular events.

- 15       However, the brachial systolic and pulse pressure may differ significantly from the corresponding values in the aorta and central arteries. Measurements of central aortic systolic and pulse pressure have been demonstrated as superior to brachial pressure in correlating with severity of existing disease and prediction of subsequent events. Such studies have used direct pressure measurements during cardiac catheterisation, or estimates of pressure from the carotid pressure or diameter waveform. Another measurement approach is described in US  
20       Patent No. 5,265,011 to O'Rourke, whereby central systolic and pulse pressure can be determined from a peripheral pressure waveform using a transfer function.

- 25       Whilst the latter method has proved highly successful in practice, it requires reasonably complex processing. In order to enable the determination of central aortic systolic and pulse pressure from a peripheral site, using a relatively simple instrument, it would be advantageous to provide a simpler method requiring a less sophisticated processing approach.

### **SUMMARY OF THE INVENTION**

- 30       According to a first aspect, the present invention provides a method for determining central systolic pressure, including the steps of:

- (a) determining the time  $t$  from pressure wave foot to peak in a central (carotid) artery;
- (b) measuring an upper limb pressure waveform;

(c) locating the pressure wave foot in the radial pressure waveform and determining the corresponding pressure at time  $t$  after the wave foot;

(d) said corresponding pressure being substantially the central systolic pressure.

5 According to a second aspect, the present invention provides a method for determining central systolic pressure, including the steps of:

(a) measuring a radial pressure waveform;

(b) locating the time of the start of the component of said waveform attributable to lower body wave reflection;

10 (c) determining the central systolic pressure by taking the value of the pressure waveform at said time.

Preferably, the start of the component attributable to lower body wave reflection is determined by analysing the waveform to locate the inflection in the waveform attributable to lower body reflection.

15 The present invention was derived from careful consideration of the underlying processes. In human adults, under normal conditions, the peak of the aortic pressure wave is usually in late systole, some 150 ms or more after initial upstroke of the pulse. In contrast, the peak of the pressure wave in the upper limb usually occurs much earlier, some 90 - 130 ms after the initial upstroke of the  
20 wave. The difference in waveform between the two sites is attributable to differences in timing of wave reflection in the lower body and upper limb. The aortic peak is largely due to the later return of wave reflection from the distant lower body, whereas the upper limb peak is due to summation of early reflected waves from within the upper limb itself. Recognition of such differences lead to  
25 the present invention.

A practical advantage of the present invention is that it allows for relatively accurate determination of the central aortic systolic pressure without requiring the application of a transfer function or a similar complex technique.

### 30 BRIEF DESCRIPTION OF DRAWINGS

An implementation of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates the waveforms associated with an exemplary implementation of the first aspect of the present invention;

Figure 2 illustrates a waveform associated with an exemplary implementation of the second aspect of the present invention;

5 Figure 3 illustrates the waveform of Figure 2 in association with the waveform's third derivative; and

Figure 4 illustrates variants of radial artery waveforms associated with an exemplary implementation of the second aspect of the present invention.

## 10 DESCRIPTION OF PREFERRED EMBODIMENT

The present invention will be described with reference to illustrative embodiments. It will be appreciated that the invention is not confined to any particular physical implementation.

15 In the present invention, the pulse pressure is determined in the same manner as systolic pressure, but is calculated as the systolic pressure minus the diastolic pressure, so as to give the amplitude of the wave. Consequently, the exemplary system of the present invention preferably includes means for calculating the pulse pressure from tonometer measurements and the calculated central systolic pressure wave, such as a simple processor having computer  
20 software loaded therein for carrying out the calculations.

An exemplary implementation of the first aspect of the present invention requires the measurement of both the carotid and radial pressure waveforms in order to determine the central (aortic) systolic pressure. Figure 1 shows pressure waveforms measured non-invasively from the carotid artery and from the upper  
25 limb. The upper limb waveform is measured, for example, at the radial artery. Time  $t$  is shown, representing the time from wave foot to peak in the carotid waveform. At this time  $t$  from the foot of the radial waveform, the initial peak has passed and the waveform shows the broad peak associated with the lower body reflections. The pressure value at this time in the radial waveform is a close  
30 approximation to the systolic pressure value in the aorta. The radial waveform is calibrated using, for example, conventional brachial cuff techniques.

It will be understood that determining the time  $t$  from the wave foot to peak is a simple matter of determining the time from minimum to maximum value,

which can be readily captured by a simple digital system. The time  $t$  can then be applied to a captured data set of pressure against time, in order to find the pressure time  $t$  after the minimum value in the radial waveform. A practical implementation is straightforward for a suitably skilled electronic engineer.

5 Display of the radial or carotid waveforms is not required.

Accordingly, this implementation of the first aspect of the present invention relies on locating the broad peak using timing information from central (carotid) arteries and detecting the radial pressure value where it corresponds to the central pressure. It will be appreciated that this method requires measurement of  
10 pressure or diameter in a central artery, in order to acquire the timing information, and this measurement is ideally made under similar conditions to the radial tonometry. Any suitable sensing arrangement may be used, provided a sufficiently accurate timing can be extracted.

On the other hand, an exemplary implementation of the second aspect of  
15 the present invention only requires measurement of the radial waveform in order to determine the central (aortic) systolic pressure. Specifically, this implementation excludes the effects of wave reflection in the upper limb and identifies the reflected wave from the lower body, which normally includes the peak of pressure in the ascending aorta, in the radial waveform to determine the  
20 central systolic pressure.

This is accomplished by analysing derivatives of the pressure waveform so as to identify the peak of the pressure wave which returns from the lower body, and which constitutes the late systolic surge of pressure after the initial peak, or which contributes to the peak of the pressure wave itself when wave reflection  
25 returns early. The time  $T_2$  denotes the peak of this wave.

The first and second derivatives of the pressure wave are analysed for this purpose, as outlined in figure 3. First, the peak of the waveform is identified. Then a search is conducted for any local minimum of the first derivative before the peak of the recorded pressure wave. If a local minimum of the first derivative  
30 is present, then  $T_2$  is set at the peak of the recorded wave, and this is taken to represent peak aortic systolic pressure; when this occurs the peak is usually well after the peak of flow in the artery, and so more than 150 msec after the wave foot.

## 5

If there is no localised minimum of the first derivative before the peak of the wave, then there is a search for the first zero crossing from positive to negative of the second derivative after the peak of the recorded wave. If there is a zero crossing, then this is taken to represent T2 and pressure of the recorded wave at this point is taken to represent peak aortic systolic pressure.

If there is no zero crossing of the second derivative from positive to negative of the second derivative after the peak of the wave, then T2 is taken to represent the following localised minimum of the second derivative after the localised peak of the second derivative which follows the peak of the recorded wave.

The application of this process is shown in the five recorded radial artery pressure waveforms in figure 4. As can be seen, for each of waveforms 1, 2 and 3 a secondary systolic or reflected wave is apparent in the upper limb. In these 3 waveforms, the time T2 (at which radial artery pressure approximates aortic peak pressure) occurs after the peak of the recorded wave and is identified from the second differential. In the waveform 5, the peak of the wave occurs in late systole and is preceded by a local minimum of the first derivative. The peak constitutes T2 and the peak pressure approximates that in the aorta. In waveform 4, there is no apparent separate reflected wave in the upper limb, but the peak of the pressure wave occurs more than 150 msec after the foot of the wave, and the first derivative usually shows an early localised minimal value. For waveforms 4 and 5, peak pressure occurs more than 150 msec after the wave foot, while for waveforms 1, 2 and 3, the peak occurs earlier than 150 msec, and corresponds to the peak of flow in the artery. When the radial artery waveform shows a very smooth peak, more than 150 msec after the wave foot, differentials may be ignored and peak pressure taken as aortic.

On the other hand, in waveforms 4 and 5, there is no apparent reflected wave in the upper limb. Accordingly, there is no need to differentiate these waveforms and the aortic systolic pressure is taken to be equal to the radial or brachial systolic pressure.

The above described processor may preferably determine whether the differentials need to be calculated based on the determination of the occurrence of a reflected wave, and returns the aortic systolic pressure value accordingly.



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It will be appreciated that variations and additions are possible within the spirit and scope of the Invention.

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**THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:**

1. A method for determining central systolic pressure, including the steps of:  
determining the time  $t$  from pressure wave foot to peak in a central carotid artery;  
measuring a radial pressure waveform; and

locating the pressure wave foot in the radial pressure waveform and  
determining the

corresponding pressure at time  $t$  after the wave foot;

wherein said corresponding pressure is substantially the central systolic  
pressure.

2. A method for determining central systolic pressure, including the steps of:  
measuring a radial pressure waveform;  
locating the time of the start of the component of said waveform attributable to  
lower body wave reflection; and

determining the central systolic pressure by taking the value of the  
pressure waveform at said time.

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